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FINAL REPORT ON CONTRACT F61708-96-W0219

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"THE DEVELOPMENT OF METHODS FOR CONTROLLING (CHANGING) THE PROBABILITY OF NUCLEAR DECAY OF MÖSSBAUER NUCLEI IN THE PROBLEM OF GAMMA-LASER CREATION"

INTRODUCTION

Within the framework of Phase I of investigation it was planned to verify the developed theoretical models and investigate the ways to optimize the method of controlling the nuclear decay. The problem of controlled radioactivity and controlled nucleus decay is one of the most interesting in nuclear physics and, in particular, it is a main one in the general gamma-laser problem.

During the period of contract I have performed theoretical investigation and preparation of experiments dealing with the process of controlling the probability of spontaneous decay of excited Mössbauer nuclei.

From the theoretical point of view, the main point in calculation of probability and dynamics of such process is the consideration of peculiarities of excited nucleus interaction with the ensemble

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of vacuum state eigen-modes of the electromagnetic field surrounding the system. In case of free space this problem is solved easily and the corresponding probability

$A_{eg} \equiv 1/\tau = (4\pi^2\omega_{eg0} |\, \mathbf{d}_{eg} |^2/3\square)\ \rho(\omega_{eg0}) = 4\omega_{eg0}{}^3 |\, \mathbf{d}_{eg} |^2/3\square c^3$

is fully determined by the nucleus characteristics (the matrix element $\mathbf{d}_{eg}$ of nucleus dipole moment) and spectral-volume density of free quantized field modes $\rho(\omega)=\rho(\omega, v_0)/v_0=\omega^2/\pi^2c^3$.

Here

$$\rho(\omega, v_0)= \int_{(4\pi)} \rho(\omega, \Theta, v_0)\, d\Theta = \omega^2 v_0/\pi^2c^3$$

is spectral density of modes in the quantization volume $v_0 >> \lambda^3$, $\rho(\omega, \Theta, v_0) = \omega^2 v_0/4\pi^3c^3$ — spectral-angular density of modes in the volume v_0 and solid angle Θ, ω_{eg0} — resonant frequency of gamma-radiative transition, $\lambda= 2\pi c/\omega$.

For free space in case of radiation transitions of higher multipolarity (quadrupole with L=2, octupole with L=3 and so on) the expressions A_{eg} for radiative and total life-times are transformed with a standard substitution $|\, \mathbf{d}_{a\alpha} |^2 \rightarrow \{6\pi\, (L+1)/L[(2L+1)!!]^2\}(\omega_{a\alpha}/c)^{2L-2}|\mathbf{Q}^{(L)}{}_{a\alpha}|^2$ and also are constants. Here $\mathbf{Q}^{(L)}{}_{a\alpha}$ is the matrix element of the excited nucleus multipole moment.

The problem becomes very complicated when material bodies exist in the surrounding space. In this case an adequate solution requires to consider simultaneously at least four systems — the excited nucleus; the electrons of the atom which contains the excited nucleus; the ensemble of electromagnetic modes interacting with the nucleus; the ensemble of objects surrounding the considered nucleus with which these modes also interact.

Due to the cumbersome mathematics of this problem only some special solutions had been found earlier — e.g., the interaction of only one or two discrete modes with the quantum system and the environment was taken into account. This case is applicable only to the low-frequency radiative transitions (microwave radiation) for which a large intermode distance $\delta\omega=1/\rho(\omega) \sim \omega^{-2}$ essentially exceeding the spectral width of these modes Γ_α is typical. Within the range where this model is valid a very significant change of spontaneous radiation characteristics (including life-time change by several orders) is possible by altering the mutual arrangement of discrete resonance modes and the radiative transition frequency, as well as by adjusting the environment properties which determine the quality and width of these modes.

In gamma-range, where very little intermode distance $\delta\omega << \Gamma_\alpha$ makes the spectrum of modes a quasicontinuous one, such an approach is fundamentally impossible.

Note also the negligible influence on full probability of spontaneous gamma-radiation of the mode gamma-spectrum transformation effect at the utilization of X-ray and gamma-ray range specific Bragg diffraction on outside crystal mirrors. Owing to very small interval of solid angles $\Delta\Theta$ where such diffraction takes place (usually $\Delta\Theta \leq 10^{-6}$) the full probability change (due to disappearance of certain field spectrum modes) doesn't exceed the small magnitude $\Delta\Theta/4\pi < 10^{-7}$.

Due to the lack of corresponding theory, in order to make predictions about the character of spontaneous gamma-decay of excited nuclei both in the matrix volume and being surrounded by different screens (resonant or nonresonant), it is in fact always supposed without any grounding, that this decay will have essentially the same characteristics as for the excited nucleus in free space. Such supposition is highly erroneous.

I have created the general theory of controlling and changing the spontaneous nuclear gamma-decay, based upon the consideration of resonant screen influence on the decay probability and life-time of excited and radioactive nuclei.

1. THEORY OF CONTROLLED EXCITED NUCLEI RADIATIVE GAMMA-DECAY

I have considered the general system which included the excited atom nucleus (described by Hamiltonian operator $\hat{H}_A$), the system of this atom electrons (Hamiltonian operator $\hat{H}_E$), the system of zero-energy (in vacuum state) electromagnetic modes (Hamiltonian operator $\hat{H}_F$) and the screen (Hamiltonian operator $\hat{H}_R$) — the system of N resonant or non-resonant atoms situated at the distance $L >> \lambda_{eg}$ from the nucleus.

The phenomenon of nucleus decay controlling is a result of interaction $\hat{U}$ of the nucleus with zero-energy electromagnetic modes, interaction $\hat{V} = \sum_{i=1}^{N} \hat{V}^{(i)}$ of these modes with the atoms of screen, interaction $\hat{T}$ of the nucleus with electrons system.

Schrödinger equation for general system has the form

$$i\hbar\, \partial\psi/\partial t = \hat{H}\psi.$$

Here $\hat{H}=\hat{H}_A+\hat{H}_F+\hat{H}_E+\hat{H}_R+\hat{U}+\hat{T}+\hat{V}$ is total Hamiltonian operator of the general system,

$$\psi(\mathbf{r}, t)=A(t)\, \psi_{a000}(\mathbf{r}) \exp(-E_a t/\hbar) + \sum_{\alpha} F_\alpha(t)\, \psi_{0\alpha 00}(\mathbf{r}) \exp(-iE_\alpha t/\hbar)+$$

$$+\sum_{e} E_e(t)\, \psi_{00e0}(\mathbf{r}) \exp(-iE_e t/\hbar) + \sum_{n} R_n(t)\, \psi_{000n}(\mathbf{r}) \exp(-iE_n t/\hbar)$$ —

total wave function of the general system; ψ_{a000}, $\psi_{0\alpha 00}$, ψ_{00e0} and ψ_{000n} — wave functions of the general system for cases of excited nucleus (excitation energy $E_a=\hbar\omega_a$), excited mode $\{\alpha\}$ (excitation energy $E_\alpha=\hbar\omega_\alpha$), excited electrons system state $\{e\}$ and excited screen state $\{n\}$ (excitation energy $E_n=\hbar\omega_n$), correspondingly.

The individual states of nucleus, field modes, excited nucleus atom electrons system and screen will be denoted by the indices a, α, e, n.

The time-dependence dynamics of spontaneous decay of the excited nucleus is described by the system of equations

$$i\hbar \exp(-i\omega_a t)\, dA/dt = \sum_{\alpha} F_\alpha U_{a\alpha} \exp(-i\omega_\alpha t) + \sum_{e} E_e T_{ae} \exp(-i\omega_e t) + i\hbar\delta(t),$$

$$i\hbar \exp(-i\omega_\alpha t)\, dF_\alpha/dt = AU^*_{a\alpha} \exp(-i\omega_a t) + \sum_{n} R_n V^*_{n\alpha} \exp(-i\omega_n t),$$

$$i\hbar \exp(-i\omega_n t)\, dR_n/dt = \sum_{\alpha} F_\alpha V_{n\alpha} \exp(-i\omega_\alpha t),$$

$$i\hbar \exp(-i\omega_e t)\, dE_e/dt = AT^*_{ae} \exp(-i\omega_e t).$$

I have obtained the general solution of this system and the solutions of general gamma-decay controlled problem for main cases — with fully non-synchronized (non-correlated) electromagnetic modes and with fully synchronized electromagnetic modes of electromagnetic vacuum that surrounds the excited nucleus.

a) For ordinary case of fully non-synchronized electromagnetic modes the general solution of this system has the form

$$A(t) = (2\pi i)^{-1} \int_{-\infty}^{\infty} \exp(i\omega t)d\omega/\{\omega - \sum_{e} |T_{ae}|^2/\hbar^2(\omega_e\text{-}\omega_a+\omega) -$$

$$- \sum_{\alpha} |U_{a\alpha}|^2/\hbar^2 [\omega_\alpha - \omega_a+\omega - \sum_{n} |V_{n\alpha}|^2/\hbar^2(\omega_n\text{-}\omega_a+\omega)]\}$$

Here $U_{a\alpha} = (2\pi\hbar\omega_\alpha/v_{0\alpha})^{1/2}(\mathbf{d}_{eg}\mathbf{e}_\alpha) \exp[-i(\mathbf{k}_\alpha\mathbf{r}_a+\varphi_\alpha)]$ is the interaction energy matrix element for interaction of nucleus with mode $\{\alpha\}$,

$V_{n\alpha} = (2\pi\hbar\omega_\alpha/v_{0\alpha})^{1/2}(\mathbf{D}_{eg}\mathbf{e}_\alpha) \exp[-i(\mathbf{k}_\alpha\mathbf{r}_n+\varphi_\alpha)]$ and T_{ae} — the corresponding matrix elements for interaction of mode $\{\alpha\}$ with screen (in state $\{n\}$) and for interaction of nucleus with nucleus electrons system (in state $\{e\}$),

$v_{0\alpha}$ — volume of electromagnetic mode $\{\alpha\}$ quantization, $\mathbf{D}_{eg}$ — matrix element of screen atom dipole momentum.

The obtained general solution can be reduced for several particular cases.

1) For the case of free space without screen ($V_{n\alpha}= 0$) from the general solution we obtain the ordinary result

$A(t) = \exp\{i(\Delta\omega_0+\Delta\omega_e)t - (\Gamma_0+\Gamma_e)t/2\} \equiv \exp\{i(\Delta\omega_0+\Delta\omega_e)t - t/2\tau_{tot}\}$.

Here $\tau_{tot}=1/(\Gamma_0+\Gamma_e)=\tau/(1+\alpha)$ is the ordinary total life-time of excited nucleus level,

$\alpha=\Gamma_e/\Gamma_0$ — internal electron conversion coefficient for excited nucleus,

$\tau\equiv1/\Gamma_0=3\hbar c^3/4\omega_a^3|\mathbf{d}_{eg}(\omega_a)|^2$ — ordinary radiative life-time of excited nucleus level,

$$\Delta\omega_0+\Delta\omega_e = P\int_0^\infty 2\omega_\alpha^3|\mathbf{d}_{eg}(\omega_\alpha)|^2 d\omega_\alpha/3\pi\hbar c^3(\omega_\alpha - \omega_a)+P\int_0^\infty |T_{ae}|^2 \rho_e(\omega_a)/\hbar^2 d\omega_\alpha/(\omega_e - \omega_a+\omega')$$ — total radiative shift of excited nucleus level,

$\tau_e\equiv\tau/\alpha=1/\Gamma_e=\hbar^2/2\pi|T_{ae}|^2 \rho_e(\omega_a)$ — internal electron conversion life-time of excited nucleus level.

The operator P (in the expressions for $\Delta\omega_{0,e}$) denotes the calculation of Cauchy principal value of the integral.

It follows from these results that in free space the decay is described by standard expression

$|A(t)|^2 = \exp(-t/\tau_{tot})$

with standard total life-time of excited nucleus

$\tau_{tot} = \tau/(1+\alpha) = 3\Box c^3/(1+\alpha)4\omega_a^3|\mathbf{d}_{eg}(\omega_a)|^2$.

2) For the case of resonant ($\omega_{n0} \approx \omega_a$) screen we have

$A(t) = \exp\{i(\Delta\omega_a + \Delta\omega_e)t - t/2\tau^*_{tot(res)}\}$.

Here $\tau^*_{tot(res)} \equiv 1/(\Gamma_a + \Gamma_e) \equiv \tau_{tot}(\Gamma_0 + \Gamma_e)/(\Gamma_a + \Gamma_e) = \tau/\{\alpha + Re[(1-2i\tau\Delta\omega_0)/(1+iG/2-\Delta\Omega_r)^4]\}$ and

$\tau^*_{(res)} \equiv 1/\Gamma_a \equiv \tau(\Gamma_0/\Gamma_a) = \tau/Re[(1-2i\tau\Delta\omega_0)/(1+iG/2-\Delta\Omega)^4]$ — changed total and radiative life-times;

$G = 2N\pi^2|\mathbf{d}_{eg}(\omega_{n0})|^2/3\tau^*_{tot(res)}\Box v_0[(\omega_{n0}-\omega_a)^2 + (1/2\tau^*_{tot(res)})^2]$,

$\Delta\Omega_r = 2N\pi|\mathbf{D}_{eg}(\omega_{n0})|^2(\omega_{n0}-\omega_a)/3\Box v_0[(\omega_{n0}-\omega_a)^2 + (1/2\tau^*_{tot(res)})^2] \equiv (\omega_{n0}-\omega_a)G\tau^*_{tot(res)}/\pi$,

$\mathbf{D}_{eg}$ — matrix element of screen atom dipole momentum.

For this case the decay is described by expression $|A(t)|^2 = \exp(-t/\tau^*_{tot(res)})$ with changed total $\tau^*_{tot(res)}$ and radiative $\tau^*_{(res)}$ life-times.

3) For the case of nonresonant ($\omega_{ns} \neq \omega_a$) screen we have

$A(t) = \exp\{i(\Delta\omega_a + \Delta\omega_e)t - t/2\tau^*_{tot(nres)}\}$ and $|A(t)|^2 = \exp(-t/\tau^*_{tot(nres)})$.

Here $\tau^*_{tot(nres)} = 1/(\Gamma_a + \Gamma_e) = \tau/[\alpha + (1-\Delta\Omega_{nr})^{-4}]$ and $\tau^*_{(nres)} = \tau/(1-\Delta\Omega_{nr})^{-4}$ are changed total and radiative life-times for nonresonant screen;

$$\Delta\Omega_{nr} = 2N\pi\sum_s|\mathbf{D}_{eg}(\omega_{ns})|^2(\omega_{ns}-\omega_a)/3\Box v_0[(\omega_{ns}-\omega_a)^2 + (2\tau^*_{tot(nres)})^{-2}].$$

It was shown that resonant screen effect in all cases appears to be more significant than for the nonresonant one. For the same relation N/v_0 the influence of the resonant screen upon life-times τ^*_{tot}, τ^* of excited nucleus is by several orders more effective than the influence of the nonresonant screen.

b) For the case of synchronized electromagnetic modes ($\varphi_\alpha = \varphi_\beta = \ldots$) I have obtained the solution

$A(t) = \exp\{i(\Delta\omega_a + \Delta\omega_e)t - t/2\tau^*_{tot(syn)}\}$, $|A(t)|^2 = \exp(-t/\tau^*_{tot(syn)})$

of general controlled gamma-decay problem based on the system of equations for time-dependent dynamics of spontaneous decay of the excited nucleus. Here

$\tau^*_{tot(syn)} = \tau/\{\alpha + Re[(1-2i\tau\Delta\omega_0)/(1+iG^{(coh)}/2-\Delta\Omega^{(coh)})^4]\}$ and

$\tau^*_{(syn)} = \tau/Re[(1-2i\tau\Delta\omega_0)/(1+iG^{(coh)}/2-\Delta\Omega^{(coh)})^4]$ are changed total and radiative life-times for the case of fully synchronized modes;

$$\Delta\Omega^{(coh)} = 4\rho_0\pi \sum_s |\mathbf{D}_{eg}(\omega_{ns})|^2 (\omega_{ns}-\omega_a)/3\pi\Box[(\omega_{ns}-\omega_a)^2 + (1/2\tau^*_{tot(syn)})^2];$$

$$G_r^{(coh)} = 4\rho_0\pi^2|\mathbf{D}_{ge}(\omega_{n0})|^2/3\tau^*_{tot(syn)}\Box[(\omega_{n0}-\omega_a)^2+(1/2\tau^*_{tot(syn)})^2],\ G_{nr}^{(coh)} \approx 0;$$

ρ_0 — the volume density of resonant atoms in the screen.

The most influence on the nucleus spontaneous decay process will be realized in case when the modes of electromagnetic field in zero-energy (the lowest by energy) state, which interact with nucleus, occur to be mutually synchronized. For this case the influence of the screen is by several orders (about $2\rho_0 v_0/N \approx 10^3 \div 10^4$) more effective than for the cases 1), 2), 3) of non-synchronized modes.

It was shown also that the effect of influencing the spontaneous radiation characteristics of excited (radioactive) nuclei may manifest itself not only for Mossbauer nuclei and transitions but also for other excited states and nucleus types provided the existence for them of an obviously expressed resonance absorption.

2. THE EXPERIMENTAL INVESTIGATION OF THE EXCITED AND RADIOACTIVE NUCLEI GAMMA-DECAY CONTROLLED

We have carried out investigation aimed at experimental discovery (based on our original theory) and study of the phenomenon of excited nuclei gamma-decay controlling.

The experiment on controlling of the nuclei decay and changing τ^*_{tot}, τ^* were performed based on our theory. The aims of these experiments were to measure the changing of the life-times τ^*_{tot}, τ^* and the spectral width of Mossbauer radiation $\Gamma^* \equiv 1/\tau^*_{tot}$ (as a result of changing τ^*_{tot} and τ^*) during action of resonant screen.

Experiments were carried out under carefully controlled conditions.

In order to reduce the influence of technical fluctuations the isotope Sn^{119m} with short life-times $\tau_{tot} = 1{,}85.10^{-8}$ s, $\tau = 1{,}2.10^{-7}$ s and $\alpha = 5{,}5$ was used.

The layout of the experiment is presented on Fig.1.

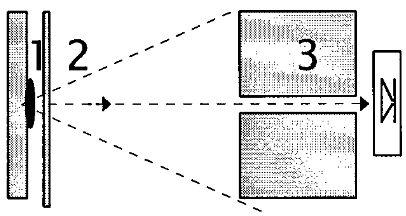

Fig. 1a

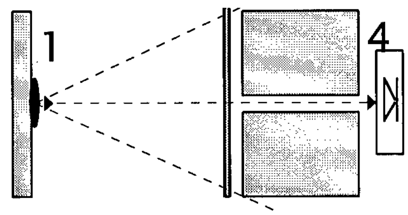

Fig. 1b

The excited Sn^{119m} isotope (chemical compound $CaSn^{119m}O_3$) with activity of 5 mCi was used as a source 1 of Mossbauer radiation with the energy of quanta E_γ=23,8 KeV. This source had a spectrum of radiation with approximately natural width. The nearly optimal resonant absorber 2 had a form of disk with diameter D ≈ 3 cm, made of stable Sn^{119} isotope (chemical compound $Sn^{119}O_2$) and has density σ_m ≈1,4 mg/cm^2≈ 6.10^{18} nuclei Sn^{119}/cm^2. This absorber (screen) had a spectrum of absorption with almost natural width.

The lead diaphragm 3 had a hole with diameter D_0=1 cm and length L_0=2,5 cm. Behind the diaphragm there was a resonant detector 4 and a system for changing the Doppler velocity of detector 4. The measurements with gamma-beam (traveling from source through resonant absorber and diaphragm to resonant detector) were performed in two regimes.

In the first regime (Fig. 1a) the resonant absorber 2 was fixed in position near source 1 (1_1≈0,2cm).

In the second regime (Fig.1b) the resonant absorber 2 was fixed at 1_2=3 cm from source in position near diaphragm 3.

Each measurement of $\Gamma^*_{(a)}$ or $\Gamma^*_{(b)}$ in both cases lasted Δt=0,5 hour. The results of measurements are presented on Fig.2. for two series of independent measurements: squares — absorber is situated near source; circles — absorber is situated near diaphragm.

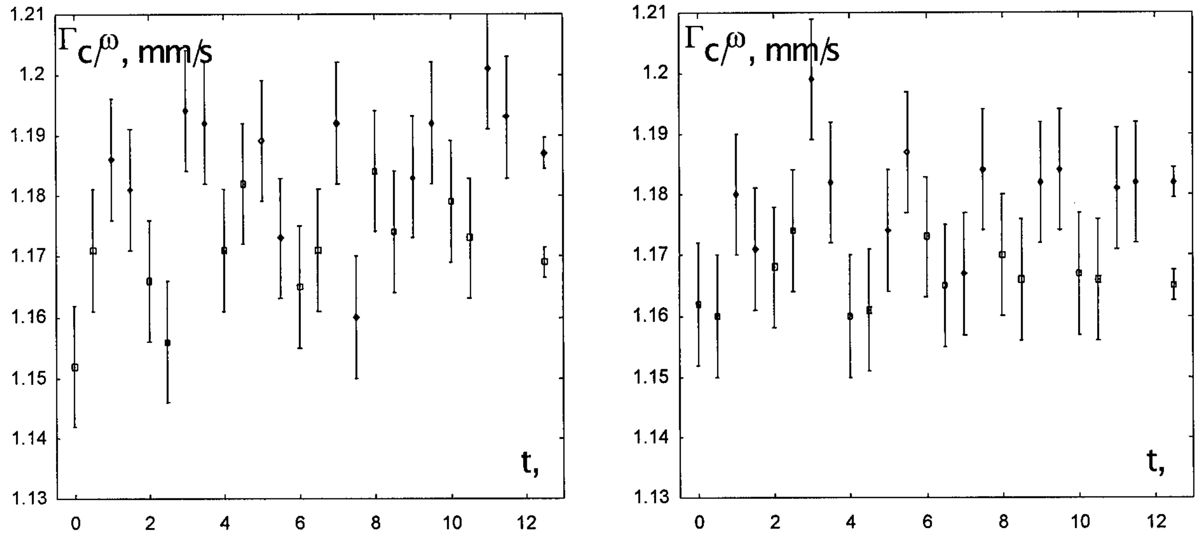

Fig..2. The influence of position of nearly optimal resonant screen $Sn^{119}O_2$ upon the width of gamma-spectrum for gamma-quanta passing through this screen and the hole of diaphragm for two series (fig. 1a, 1b) of independent measurements: squares — screen is situated near source; circles — screen is situated near diaphragm. The points to the right are the result of averaging the data for all measurements.

Using the result of theoretical calculation we find the expressions that describe the changing of total and radiative (for controlling Mossbauer part) life-times

$1/\tau^*_{tot(b)} - 1/\tau^*_{tot(a)} = \Gamma^*_{(b)} - \Gamma^*_{(a)}$,

$1/\tau^*_{ef(b)} - 1/\tau^*_{ef(a)} = (\Gamma_{(b)}{}^* - \Gamma_{(a)}{}^*)\ [4\pi(1+\alpha) / f\Delta\Theta\ ]$.

The average values measured for these two series of measurements were $\Gamma^*_{(a)} = (1{,}167\pm0{,}003)$ mm/s and $\Gamma^*_{(b)} = (1{,}184\ \pm0{,}003)$ mm/s with corresponding changes of total life-time of Sn^{119m} $\{\tau^*_{tot(a)} - \tau^*_{tot(b)}\}/\tau_{tot} = (0{,}63 \pm 0{,}12)\cdot 10^{-2}$ and life-time for controlled Mossbauer component of Sn^{119m} gamma-radiation $\{\tau/\tau^*_{ef(b)} - \tau/\tau^*_{ef(a)}\} = (0{,}82 \pm 0{,}16)$.

For other non-optimal resonant screen made from compound $CaSn^{119}O_3$ (with non-optimal thickness $\sigma_m \approx 0{,}7$ mg/cm$^2 \approx 3.10^{18}$ nuclei Sn^{119} per cm^2) the measurements with gamma-beam were also performed in two regimes. The size and form of this screen were the same as for the screen made of $Sn^{119}O_2$.

In the first regime the resonant absorber 2 was fixed in position near source 1 (at distance $l_1 \approx 0{,}2$ cm). In the second regime the resonant absorber 2 was fixed at distance $l_2 \approx 3$ cm from source in position near diaphragm 3. For this screen each measurement of $\Gamma^*_{(a)}$ and $\Gamma^*_{(b)}$ in these both regimes lasted $\Delta t = 0{,}5$ hour.

The average values measured were $\Gamma_{(a)}^* = (0{,}995 \pm 0{,}003)$ mm/c, $\Gamma^*_{(b)} = (1{,}002 \pm 0{,}003)$ mm/c, with corresponding changes of total life-time of Sn^{119m} $(\tau_{tot(a)}^* - \tau_{tot(b)}^*)/\tau_{tot} \approx (0{,}26 \pm 0{,}12).10^{-2}$ and life-time for controlled Mossbauer component of Sn^{119m} gamma-radiation $\{\tau/\tau^*_{ef(b)} - \tau/\tau^*_{ef(a)}\} = (0{,}34 \pm 0{,}16)$.

These experimental results are corresponding to the results of theoretical analysis for these cases. The optimization could be continued to using more optimal nuclei and resonant screens with predominance of resonant radiational (and not conversional) decay channels (i.e., with $\alpha \to 0$), using resonance absorbers with a maximum solid angle screening ($\Delta\Theta \to 4\pi$) and with maximum weight part of the resonant channel ($f \to 0$). Then it would be possible to get a significantly greater increase of influence on spontaneous decay characteristics and, respectively, sharp increase of the total time $\tau_{tot}^* >> \tau_{tot}$. For these optimal nuclei it will be possible to solve successfully the famous dilemma of gamma-laser — making τ equal $\tau_{tot(max)}$ during pumping and τ equal $\tau_{tot(min)}$ during gamma-generation.

3. SUMMARY

1) The novel general theory of controlling and changing the spontaneous nuclear gamma-decay was created. The phenomenon of nuclear decay controlling is a result of interaction of the excited nucleus with zero-energy electromagnetic modes, which in turn interact with the controlling screen. In general case the spontaneous decay probability with presence of adjacent material bodies always differs from the corresponding probability for free space.

2) It was shown for the first time that the decay parameters greatly depend on the sign and magnitude of radiation shift of the resonance level position (nuclear analog of the Lamb shift for atom electrons). This shift is determined by processes of nucleus interaction with all zero-energy electromagnetic field modes (the lowest by energy or ground).

3) It was shown that resonant screen effect in all cases appears to be more significant than for the nonresonant one.

4) The most influence on the nucleus spontaneous decay process will be realized in case when the modes of electromagnetic field in zero-energy state, which interact with nucleus, occur to be mutually synchronized. For this case the radiative life-time may be increased by many orders of magnitude.

5) The phenomenon of gamma-decay controlling was experimentally studied by means of Mossbauer spectroscopy. Experiments have proved the possibility of changing the life-time of radioactive and excited nuclei by surrounding them with screen having resonant absorption frequency equal to the radioactive and excited nuclei transition frequency.

6) For the first time in the experiments with gamma source Sn^{119m} and with gamma absorber Sn^{119} we have discovered the change (increase) of Mossbauer transition life-time by 80-40 % and total life-time (including non-Mossbauer radiation and electron conversion) by 0.6-0.4 %.

7) By optimization of decay controlling system parameters it is possible to get a significantly higher of influence upon spontaneous decay characteristics and, respectively, sharp increase of total time $\tau_{tot}^* >> \tau_{tot}$.

8) It was shown that the effect of excited (radiative) nuclei influence on spontaneous radiation characteristics may manifest itself not only for Mossbauer nuclei and transitions but also for other excited states and nucleus types provided the existence for them of an obviously expressed resonant absorbtion.

It is necessary to note that the financial expenditures for experimental set up (obtaining the instruments, stable and nonstable isotopes etc.) greatly exceeded the amount of financing provided under this contract. We believe that it was necessary considering the possibility of our future cooperation.

4. SUGGESTIONS FOR FUTURE INVESTIGATIONS

If the investigations on this topic will continue, the nearest theoretical and experimental goals could be the following:

1) explore the influence of existence of both resonant and nonresonant atoms in the absorbing screen upon the effectiveness of controlling the spontaneous decay;

2) move from consideration of a single excited nucleus to the case of a system of excited nuclei for such spatial configurations (needle, film etc.), which correspond to the developed gamma-lasers and other possible sources of directed gamma-radiation;

3) consider the peculiarities of partly synchronized electromagnetic vacuum modes influence upon excited nuclei gamma-decay;

4) develop the theoretical models and means of experimental realization of methods of partial and full synchronization of electromagnetic vacuum modes;

5) perform the theoretical and experimental investigation of ways of influencing the conversional nuclei decays with the aim of suppressing them and amplification of controlled gamma-decay channels;

6) carry out the investigation of the possibility of controlling the gamma-decay for non-Mossbauer nuclei and nuclei with big gamma-radiation energy;

7) perform modeling and experimental investigation of directed gamma-radiation systems of laser (coherent radiation) and quasi-laser (non-coherent concentrated radiation) types.

8) carry out the investigation of the possibility of controlling the X-ray decay with the aim of X-ray laser creation.